FY2012 NEUP Workshop Breakout Sessions

Light Water Reactor Sustainability

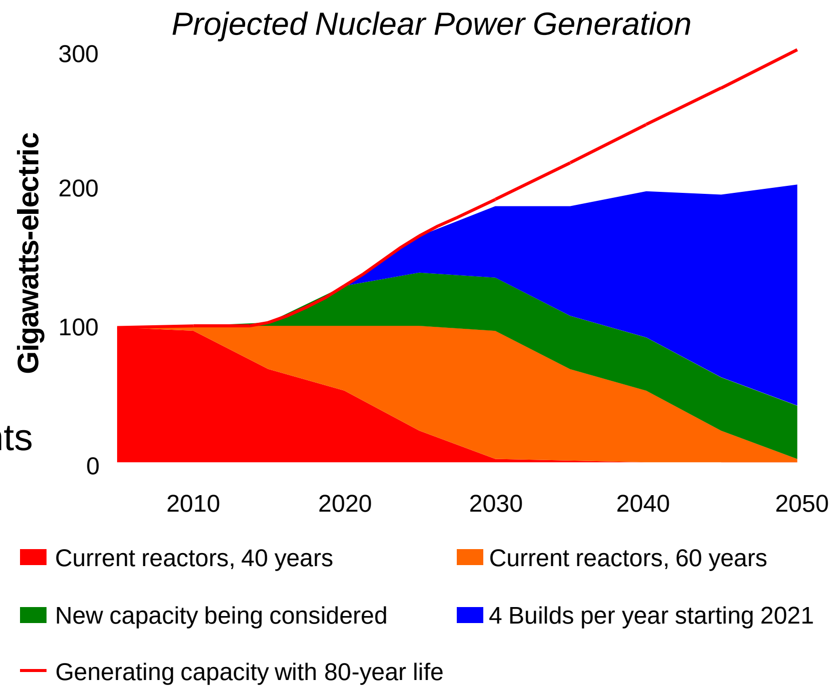
R&D Objective 1: Extend Life, Improve Performance, and Maintain Safety of the Current Fleet

Science-Based R&D to Extend Nuclear Plant Operation

August 2011

Extended Operations of the Existing Reactor Fleet is in the National Interest

- EIA AEO 2011 reference case: U.S. electricity consumption to increase 40+% (2009 → 2035)
  - Annual CO_2 emissions (all sectors) projected to increase to 6.31 billion metric tons (2035)
- Nuclear generation is critical to:
  - Reduce greenhouse gases
  - Meet electricity demand
  - Ensure energy supply security and grid reliability
  - Stabilize energy prices
- Current nuclear plants retire between 2029 – 2056
  - New nuclear build rate will not replace plant retirements
  - Cost to replace the current fleet is significant
  - Steep reduction in emission-free generation
- Existing reactors reduce burden of new "clean" generation sources that will need to come online

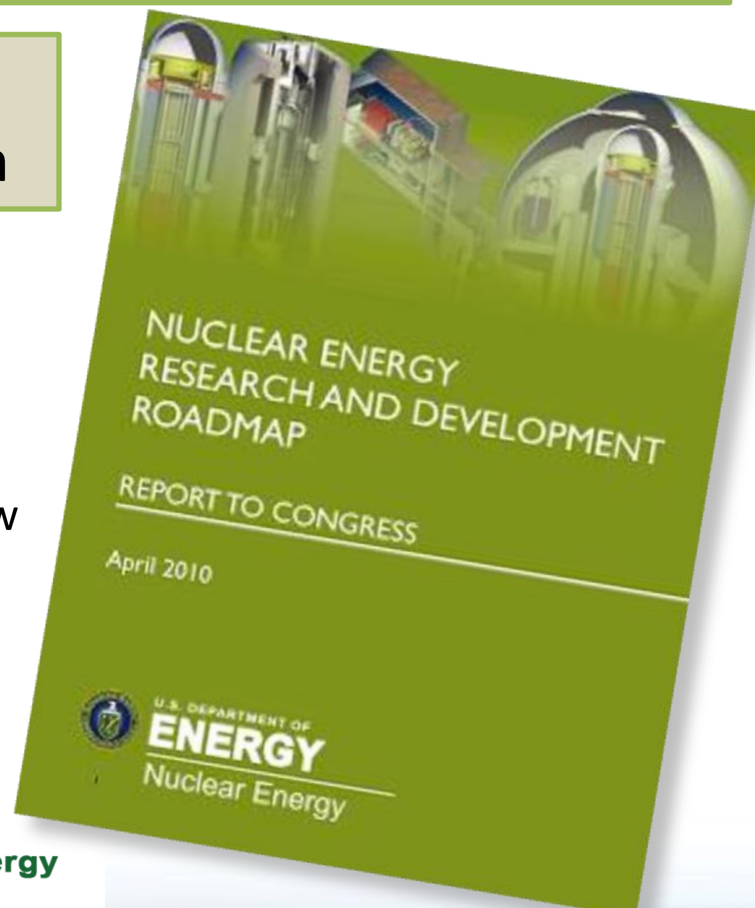


DOE Nuclear Energy Roadmap is the Foundation for LWRS Program Planning and Key Activities

R&D Objective #1 of DOE Nuclear Energy Roadmap is to Extend Life, Improve Performance, and Maintain Safety of the Current LWR Fleet

R&D Objective #1 — Light Water Reactor Sustainability (LWRS) Program

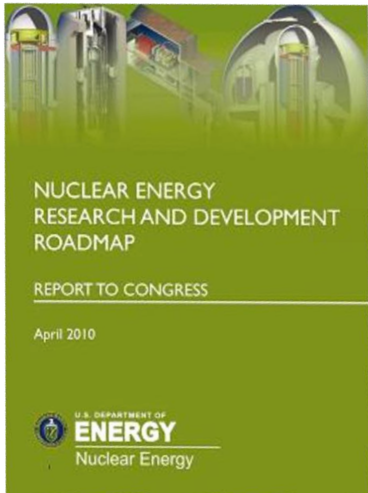
- Vision - Enable existing nuclear power plants to safely provide clean and affordable electricity beyond current 60-year license limit
- Program Goals
  - Develop fundamental scientific basis to allow continued safe long-term operation
  - Develop technical and operational improvements that contribute to long-term economic viability

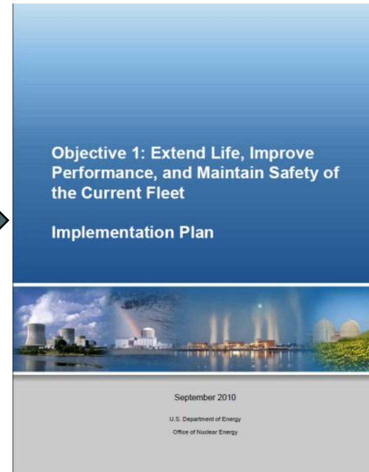


LWRS Light Water Reactor Sustainability

U.S. DEPARTMENT OF ENERGY | Nuclear Energy

DOE Nuclear Energy Roadmap is the Foundation for LWRS Program Planning and Key Activities





LTO / LWRS Joint Strategy Plan

Nuclear Materials Aging and Degradation R&D Plan

Advanced Instrumentation, Information, and Control Systems R&D Plan

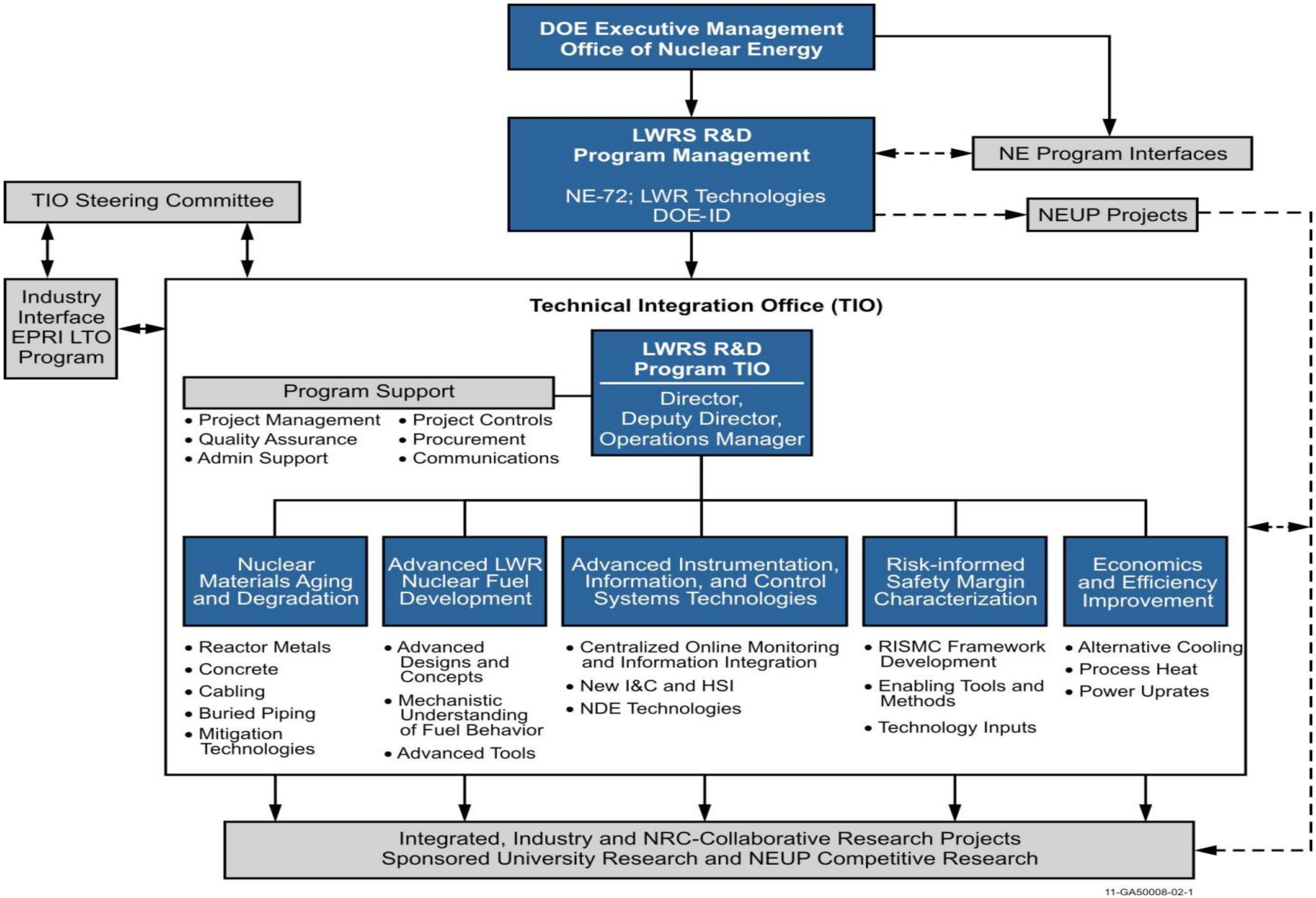
Risk-Informed Safety Margins Characterization R&D Plan

Advanced LWR Fuel Development R&D Plan

Economics and Efficiency Improvements R&D Plan

LWRS
Light Water Reactor Sustainability

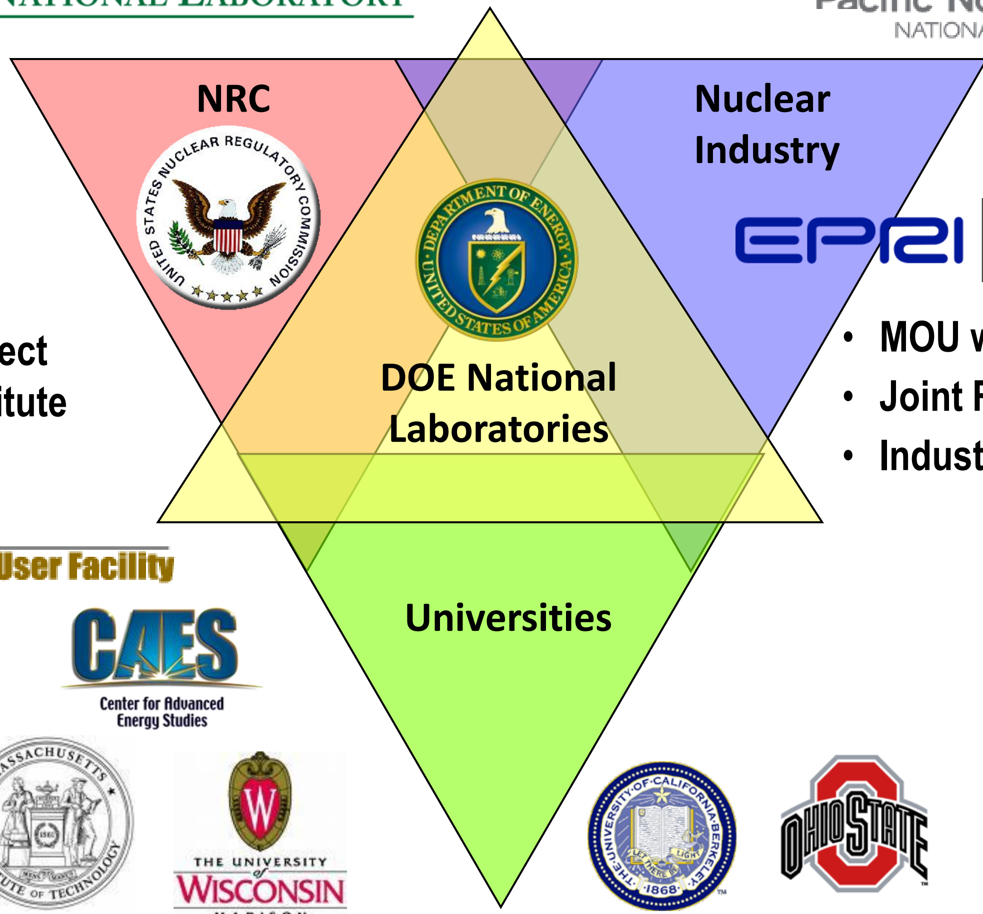
LWRS Program Organization



Light Water Reactor Sustainability

LWRS Program: An Integrated Collaborative R&D Program

- MOU with NRC
- International Partners
  - Halden Reactor Project
  - Materials Aging Institute



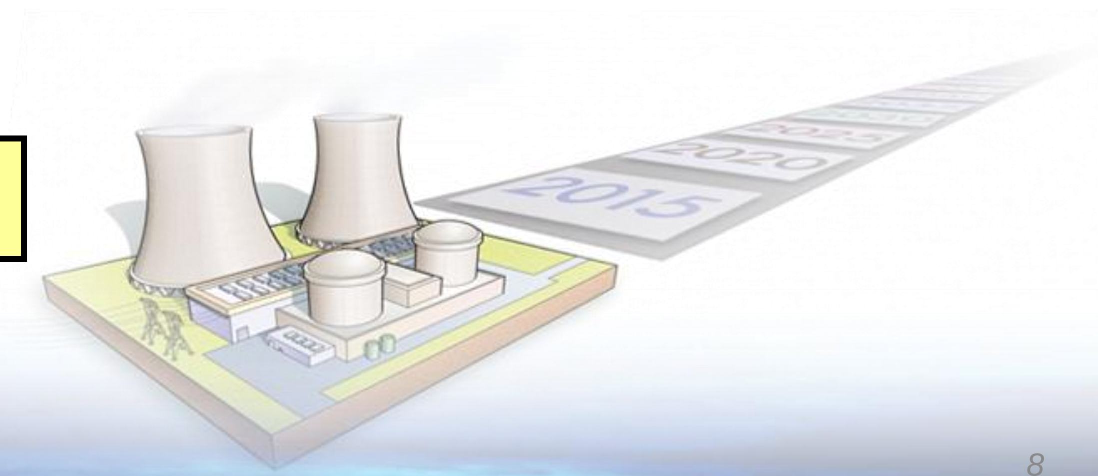
- MOU with EPRI
- Joint R&D Plan
- Industry pilot projects

LWRS Program Schedule Supports Investment & Licensing Decisions for Long-Term Operation

Phase I	Phase II	Phase III	Phase IV
2010–2015	2015–2020	2020–2030	2030–2050
Build Confidence in Life Extension with Data and Tools	Enable Industry Decision to Invest and License for License Extension	Acceptance of Advanced Tools, Methods and Technologies	Fleet Operation Beyond 60-year Life

$10M → $100M

Large Payoff: Moderate R&D Cost Leveraging High Capital Investments



Light Water Reactor Sustainability

LWRS Leadership (1/2)

- ***DOE – Office of Nuclear Energy***
  - ***Richard Reister, Federal Project Director***
  - ***301-903-0234, richard.reister@nuclear.energy.gov***
- ***LWRS Technical Integration Office (TIO), http://www.inl.gov/lwrs***
  - ***Ronaldo Szilard, LWRS Director***
    - ***INL, 208-526-8376, ronaldo.szilard@inl.gov***
  - ***Don Williams, LWRS Deputy Director***
    - ***ORNL, 865-574-8710, williamsdljr@ornl.gov***
  - ***Cathy Barnard, LWRS Operations Manager***
    - ***INL, 208-536-0382, cathy.barnard@inl.gov***
  - ***John Gaertner, EPRI TIO Representative***
    - ***704-595-2169, jgaertner@epri.com***

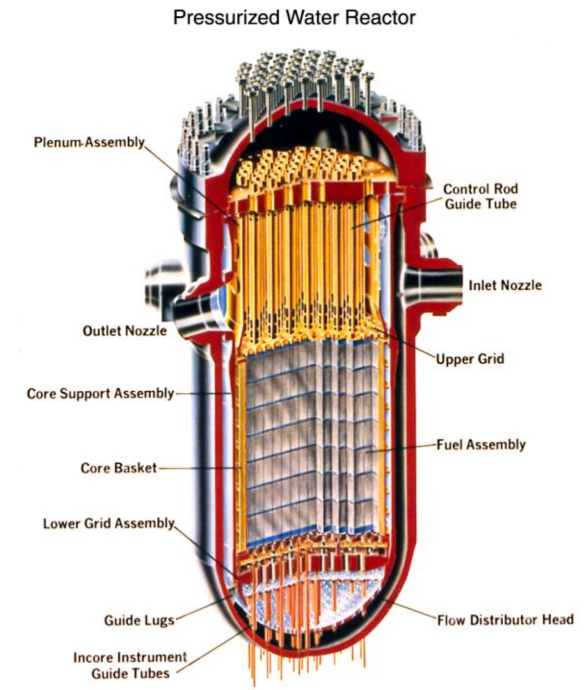
LWRS Leadership (2/2)

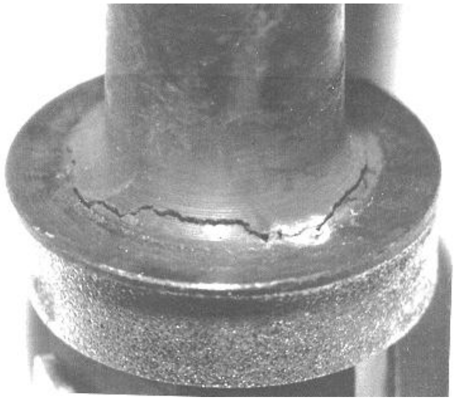
TECHNICAL PATHWAYS

- ***Nuclear Materials Aging and Degradation***
  - ***Jeremy Busby, ORNL, 865-241-4622, busbyjt@ornl.gov***
- ***Advanced I&C and Information Systems Technologies***
  - ***Bruce Hallbert, INL, 208-526-9867, bruce.hallbert@inl.gov***
- ***Risk-Informed Safety Margin Characterization***
  - ***Robert Youngblood, INL, 208-526-7092, robert.youngblood@inl.gov***
- ***Advanced LWR Nuclear Fuel Development***
  - ***George Griffith, INL, 208-526-8026, george.griffith@inl.gov***
- ***Economics and Efficiency Improvement***
  - ***Hongbin Zhang, INL, 208-526-9511, hongbin.zhang@inl.gov***

Extending the service life of today's LWR fleet may create new material challenges

- Extending reactor life to beyond 60 years will likely increase susceptibility and severity of known forms of materials degradation and potentially introduce new forms of degradation
- The LWRS R&D effort seeks to provide the scientific basis for understanding and predicting materials aging and degradation within components, systems, and structures
  - Reactor metals (RPV's, internals, steam generators, balance of plant, and weldments)
  - Concrete
  - Buried piping
  - Cabling
  - Mitigation, repair, and replacement technologies
- A new working group has been formed to integrate the materials efforts within DOE's LWRS, EPRI's LTO, and NRC's LB60 programs



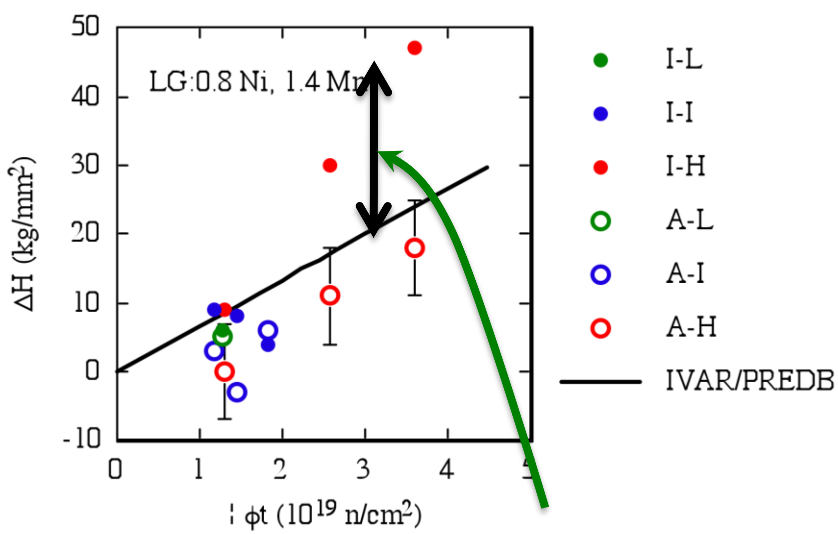


Modern materials science and mechanistic understanding will be a key component for success

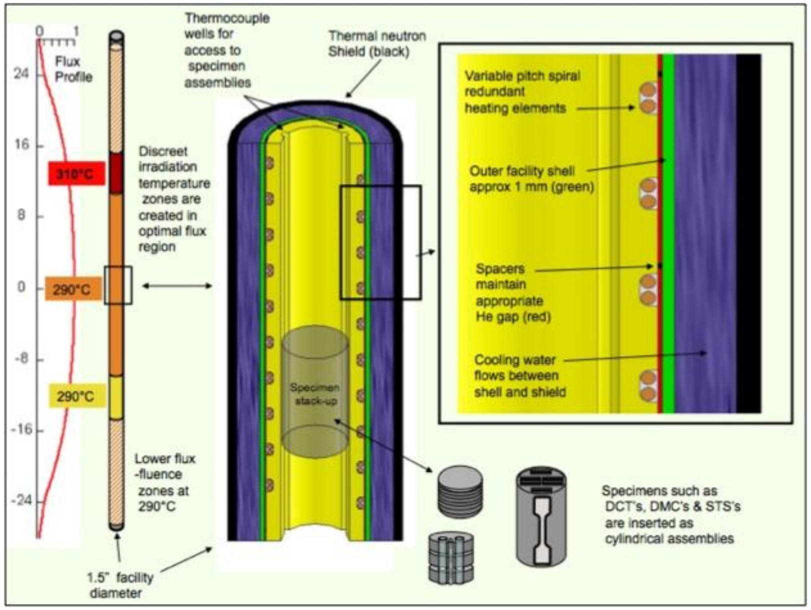
- Traditional, experimental approaches can be expensive and slow in solving today's degradation issues
- Modern materials science techniques should be utilized to provide faster and cheaper results
  - Leading expertise from around the country
  - Improved analytical techniques
  - Improved predictive modeling
  - Improved knowledge integration
- Understanding degradation mechanisms via a science-based approach will allow for better lifetime performance predictions, risk management, and/or safety assessments

Analysis of high-fluence RPV steels has provided the first experimental data for LWRS R&D

- Initial data on samples irradiated as part of previous NRC effort reveal greater hardening than expected using most advanced predictive models, based on decades of research.



Difference between IVAR prediction and experimental data indicates a new mechanism is at work. More data is required to fully evaluate these effects.



- Additional work has been initiated using the ATR NSUF to generate new specimens irradiated over a wide range of flux and fluence.
- High value specimens in the Palisades NPP are also being investigated

Advanced Information, Instrumentation, & Controls (IIC) R&D

- Current technology for IIC is not sustainable –will become a limiting factor for continued operation
- Recent replacements and modernizations using digital technologies are perceived as unsuccessful.
- Regulatory uncertainty and a risk-averse industry reinforce the status quo of outdated and antiquated analog I&C.
- ALWR licensing will not change current IIC limitations.
- Asset owners and vendors recognize that the needed change is not occurring and is not likely to occur without substantial federal involvement.

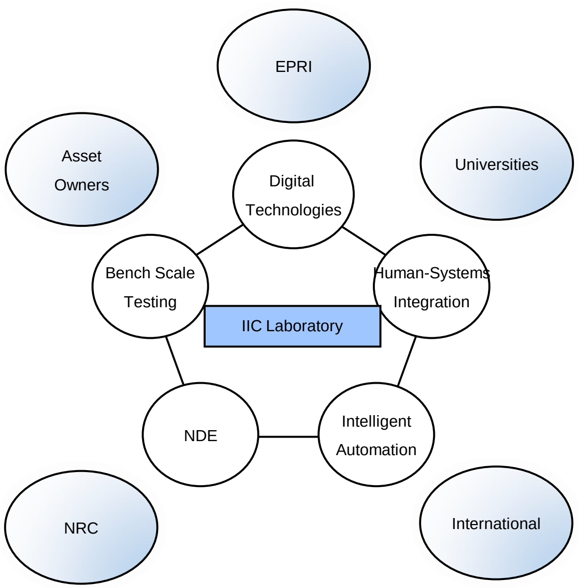
From this…

…to this!

- The commercial nuclear power industry will undertake modernization as a result of this program.
- Confidence will be created in the process of developing and deploying technology through this program to support utility and regulatory decisions.
- A federally funded and supported IIC Laboratory will form the basis for multi-party agreements used for research, development, demonstration, test & evaluation.

Industry Supports a Strong R&D Program

- Data generation & use in future operations concepts
- Real-time performance data from active and passive systems
- Diagnostics & prognostics
- Fleet-wide implementation
- Dedicated facilities for R&D




INL/EXT-09-16631

Report from the Light Water Reactor Sustainability Workshop on Advanced Instrumentation, Information, and Control Systems and Human-System Interface Technologies

Held March 20–21, 2009, in Columbus, Ohio

August 2009

Bruce P. Hallbert and J. J. Persensky, INL
Carol Smidts and Tunc Aldemir, OSU
Joseph Naser, EPRI

INL Idaho National Laboratory

Formulate a new perspective of IIC technologies for long term operation and asset management

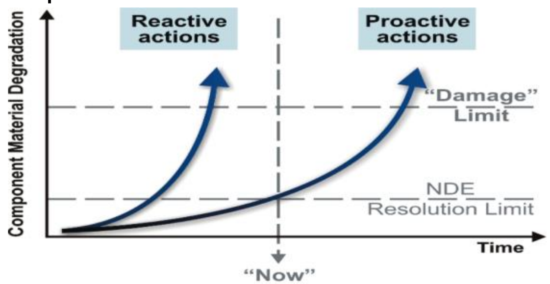
Design & test HSI to improve information access, situation awareness, and decision-making

Improve automation to amplify human capabilities

New NDE technologies to improve characterization of change due to material aging and degradation

On-line monitoring and diagnostics to better estimate the margins between operating parameters and design parameters

Eventual prognostic technologies to more accurately predict failure mechanisms and consequences.



Prognostics promises to identify components that may be expected to undergo degradation, so that mitigation actions may be implemented **before** significant challenges to structural integrity and safety arise.

08-GA50547-01g

Characterization of safety margin is central to decision making in plant operational performance, power uprate, and life extension

Aging of Structures, Systems and Components (SSC) has potential

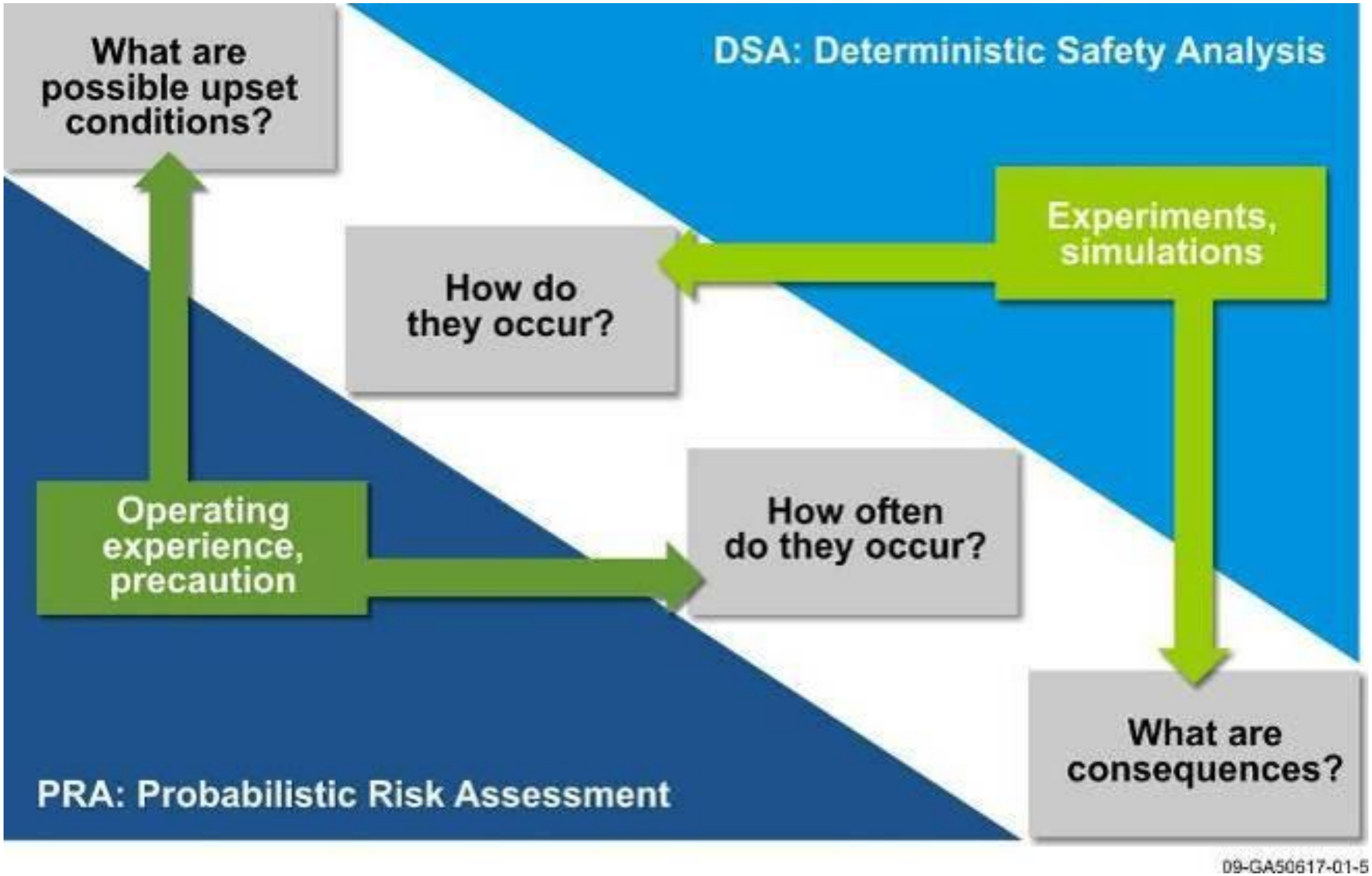
- to increase frequency of initiating events of certain safety transients;
- to create new and more complex transient sequences associated with previously-not-considered SSC failures; and
- to increase severity of safety transients due to cascading failures of SSCs.

Quantification of the effect of SSC aging on plant safety is hindered by

- deficient data and models required to predict behaviors of the aging SSCs in a broad range of plant operating, upset and accident conditions;
- large uncertainties in using the existing M&S tools to analyze the plant system dynamics in scenarios involving aging-induced SSC failures; and
- lack of a risk assessment methodology that takes into account (reliability of) passive SSCs and passive safety features.

New Methods, Tools and Data are Needed to Meet High Demands in LWR Safety Decision Making

Characterization of safety margin is central to decision making in plant operational performance, power uprate, and life extension



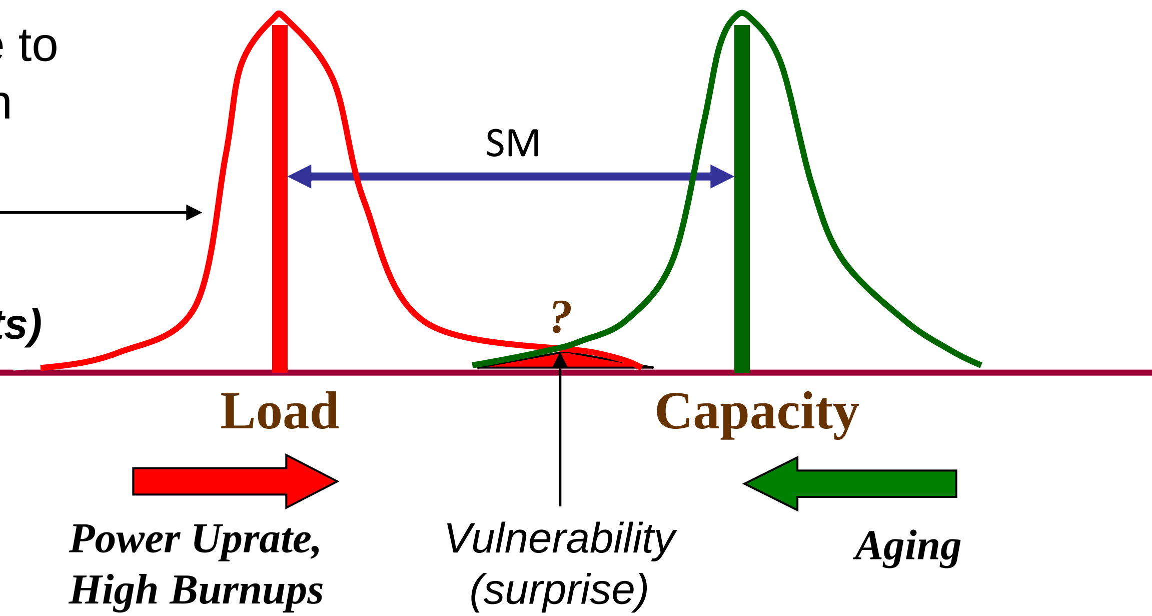
Risk-Informed Safety Margin Characterization (RISMC)

Light Water Reactor Sustainability

Combining Probabilistic and Mechanistic Modeling to provide Integrated Quantification of Aleatory and Epistemic Uncertainty

Area 1: Develop RELAP7 Code to Enable Plant System Simulation and Computation of the Plant Probabilistic Loads

- ✓ ***System analysis (multiple threats)***
- ✓ ***Tightly couple multi-physics***
- ✓ ***Coverage of scenarios***
- ✓ ***Computational efficiency***
- ✓ ***Appropriate model fidelity***



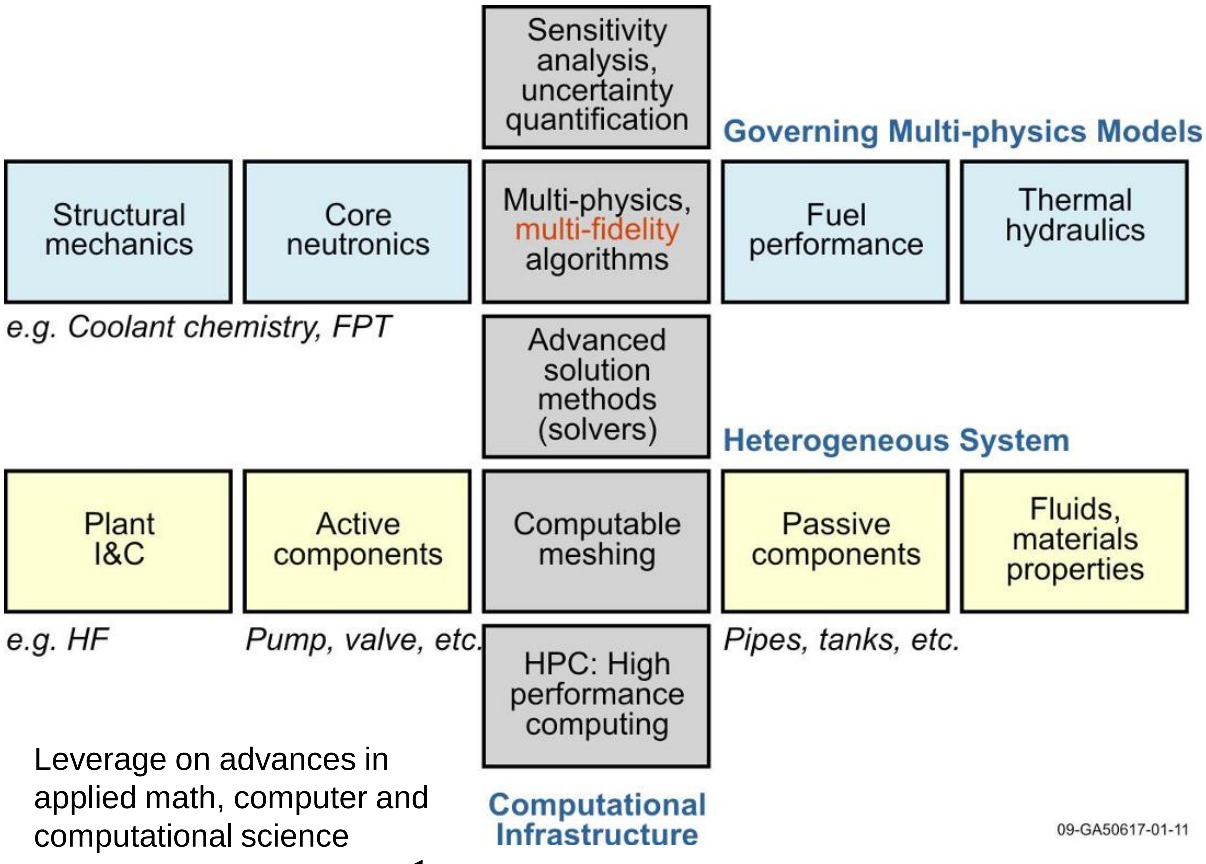
Area 2: Develop a risk-informed margin-based framework for construction of LWR plant life extension “safety case”

Area 3: Incorporate (aging) SSCs into a Plant Risk Model. Integrate RISMC with Materials Aging R&D

RELAP7 Code: a Next Generation of System Analysis Code to Support Risk-Informed Safety Decision Making

→ **Go beyond the current technology manifested by legacy codes (RELAP5, SAPHIRE) developed at INL and used broadly by the industry and regulatory evaluation**

❖ **The RELAP7 Project is a community effort, to develop new safety analysis methods, cultivate new safety culture and train new generation of nuclear engineers**



Overcome limitations of 1970s' "divide and conquer" paradigm

Push envelop of M&S in all physical processes involved in plant safety

<u>FY10-FY11 Goals:</u>

Develop R7 code architecture and test version engine

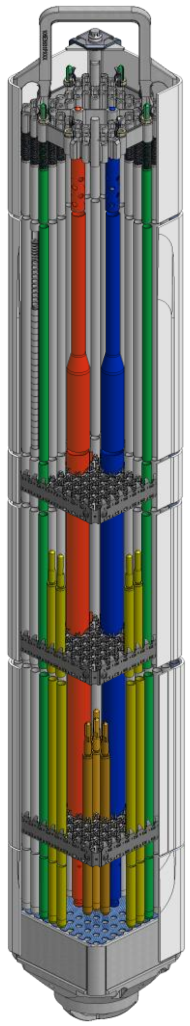
Analyze a plant safety issue of importance for life extension

Demonstrate viability of using the R7 capability to construct the RISMC "safety case" on the selected life extension issue

Advanced Nuclear Fuels

Goals:

- Improve the **fundamental scientific understanding** and **prediction** of the behavior of nuclear fuel pellets, cladding, and the fuel-coolant system under extended burn-ups for normal and transient conditions
- In **public-private** collaborations apply this information developing and demonstrating very advanced fuels with **improved safety margins**, and potential for **higher fuel** burn-ups and **performance**
- Develop **predictive** tools for advanced nuclear fuel performance
- **Speed implementation** of new fuel technologies to industrial application

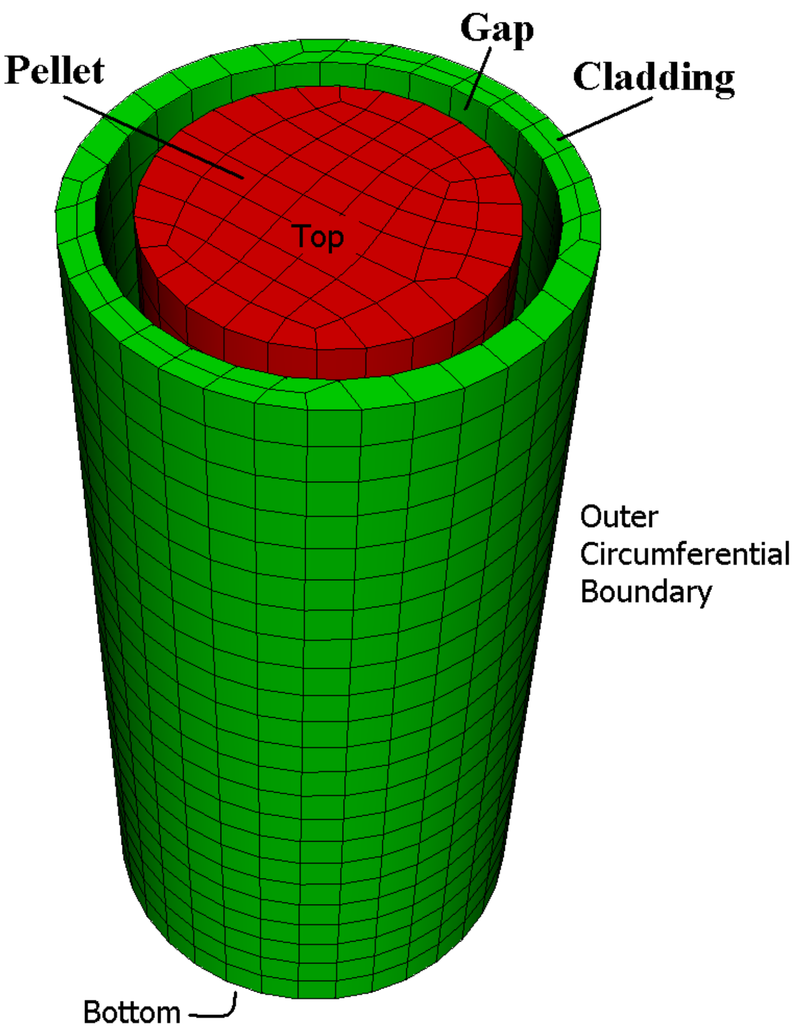


Specific planned activities:

- Begin the development of new long-life fuel designs with **advanced fuel** and **cladding** materials
- Develop **predictive tools** of advanced nuclear fuel performance
- Develop a **model for fuel cracking** at the mesoscale level with sufficient understanding to develop a predictive model for fission gas release

Advanced Fuel Designs & R&D Concepts

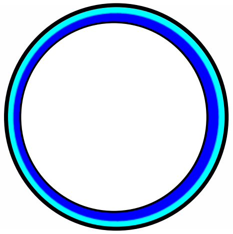
- Advanced fuels
  - UOX variants (additive fuels, >5% U-235, enriched gadolinium)
  - Alternate fuels (UN, UC, hydride)
  - Novel designs (annular fuel, innovative shapes, liquid metal bond)
  - Dopants for PCI, thermal conductivity
- Advanced Cladding
  - optimized next generation zirconium alloys
  - SiC
- Modeling and Simulation
  - Address fuel performance issues through basic scientific understanding
  - Accelerate design to implementation



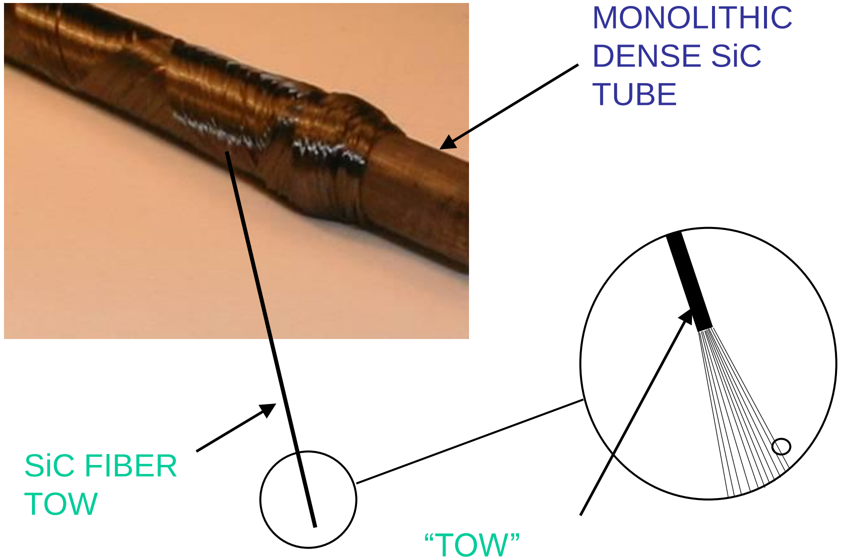
SiC Cladding Development

- Develop high performance, high burnup nuclear fuels with improved safety, clad integrity, and fuel cycle economics
- Design, develop and test a multilayered SiC clad fuel that significantly increases fuel performance. Key characteristics include:
  - strength retention to at least 1500°C, appears to be DNB proof, and therefore can facilitate power uprates of 30% or more.
  - minimal exothermic water reaction or H2 release during LOCA's,
  - fully retains fission gases – no creep and FG retention to at least 5000 psi
  - composite layer solves ceramic "brittleness" problem
  - Can operate in LWR coolant for over 10 years with no appreciable corrosion
    - Zirc alloys embrittle after 5 years operation and are therefore limited by regulation to 62 gwd/t
  - When coupled with increased U235 loading, can double the burnup to 100 gwd/t
  - Very hard, resists fretting and debris failure, further reduction in operational failures

SiC TRIPLEX CLADDING



FILAMENT WINDING



Efficiency Improvement IP Schedule

	Phase I	Phase II	Phase III
Alternative Cooling Technology	Preserve once-through technology	Cost reduction and efficiency improvement for dry and hybrid cooling technology	Application of advanced cooling technologies
	Development of water conservation technology for wet cooling tower		
Non-electirc Applications	Technology and economics viability	Interface design	Applications
Power Uprate	Collaborate with other pathways to enable 10 GWe extra capacity addition through power uprates, with a stretch goal of 20 GWe		

09-GA50277-05f

Planned FY 2012 Program Accomplishments (1/2)

- ***Investigate mechanisms of irradiation-assisted stress corrosion cracking (IASCC), crack initiation in nickel-based alloys, high-fluence effects on stainless steels, IASCC of alloy X-750, reduction in toughness of reactor pressure vessel (RPV) steels, swelling effects and phase transformations in high-fluence core internals.***
- ***Assess degradation of concrete in unique reactor environments (radiation, high temperature, moisture) and develop nondestructive examination (NDE) techniques.***
- ***Continue pilot projects at the R.E. Ginna plant and Nine Mile Point 1 plant to obtain information on materials that supports development of guidance on inspection of containments and reactor internals.***
- ***Continue the development of the next generation safety analysis code extending it from small-scale demonstration of algorithmic features to plant-scale evaluations, focusing on case studies coordinated with industry.***
- ***Develop a strategy and methods, and execute cost-shared pilot projects to demonstrate first-of-a-kind instrumentation and control technologies to modernize existing nuclear power plant instrumentation and control systems.***

Planned FY 2012 Program Accomplishments (2/2)

- *Develop centralized on-line monitoring and information integration systems applicable to existing LWRs to enable early detection of material degradation.*
- *Continue the development of new long-life fuel designs with advanced fuel and cladding materials.*
- *Continue development of a model for fuel cracking at the mesoscale level with sufficient understanding to develop a predictive model for fission gas release.*
- *Continue investigation of alternative and new cooling technologies that can be applied in the near term to reactors impacted by insufficient cooling water supplies.*
- *Develop innovative technologies that lessen the environmental impacts of removing large volumes of cooling water from naturally occurring sources.*
- *Assess degradation of cables in unique reactor environments (radiation, high temperature, moisture) and develop tools and methods to measure degradation and predict failures.*
- *Identify technical gaps and limitations on extended power uprates greater than 20 percent.*

NEUP Workscope Descriptions (1/6)

Nuclear Materials Aging and Degradation – Advanced Mitigation Strategies (LWRS-1)

Advanced mitigation strategies and techniques. Extended operating periods may reduce operating limits and safety margins of key components and systems. While component replacement is one option to overcome materials degradation, other methods (e.g. thermal annealing or water chemistry modification) may also be developed and utilized to ensure safe, long-term operation. Validation and/or development of techniques to reduce, mitigate, or overcome materials degradation of key LWR components are sought. Mitigation strategies for pressure vessel steels, core internals, weldments, or concrete are encouraged. Universities engaging in this effort will be expected to produce concepts, supporting data and/or model predictions demonstrating the viability of mitigation strategies for key LWR components.

NEUP Workscope Descriptions (2/6)

Risk-Informed Safety Margin Characterization (LWRS-2)

R&D should address the Risk-Informed Safety Margin Characterization (RISMC) methodology. Areas of high priority include advanced modeling and simulation methods to support the development, verification, and validation of next-generation system safety codes that enable the nuclear power industry to perform analysis of a nuclear power plant's transients and accidents. An especially important need in this analysis is a very clear understanding of the real uncertainties in the analysis. This requires not just propagation of parameter uncertainty via sampling techniques, but also meaningful quantification of the underlying distributions, addressing not only epistemic uncertainty but also variability in phenomena, including variability in component behavior (variability in stroke times, pump head curves, heat transfer coefficients, and so on).

NEUP Workscope Descriptions (3/6)

Risk-Informed Safety Margin Characterization, LWRS-2 (continued)

Universities performing this research will be expected to produce results that integrate multiple mechanistic processes. Also of interest are advanced approaches to coarse-grained single-phase and two-phase thermal-hydraulics modeling and experimental validation, including coupling of models of different resolutions, for example, between one dimensional system thermal-hydraulics and three dimensional Computational Fluid Dynamics-type models, and treatment of dynamic flow regimes.

NEUP Workscope Descriptions (4/6)

Advanced I&C/Information Systems Technologies (LWRS-3)

Digital instrumentation and control technologies for highly integrated control and display, improved monitoring and reliability. Research is needed to improve upon available methods for online monitoring of active and passive components to reduce demands for unnecessary surveillance, testing, and inspection and to minimize forced outages and to provide monitoring of physical performance of critical SSCs. In addition, methods are needed to analyze the reliability of integrated hardware/software technologies that comprise digital systems. Research should investigate NDE technologies to characterize the performance of physical systems in order to monitor and manage the effects of aging on SSCs.

Light Water Reactor Sustainability

NEUP Workscope Descriptions (5/6)

Advanced I&C/Information Systems Technologies, LWRS-3 (continued)

High priority research areas include the following: 1) methods and technologies that can be deployed for monitoring nuclear plant systems, structures, and components, and that can be demonstrated in test bed environments representative of nuclear plant applications; and 2) methods for analyzing the dynamic reliability of digital systems, including hardware and software systems based on formal methods that can be demonstrated on systems that are proposed or representative of systems proposed for nuclear plant control and automation. This research is expected to support the development of methods and technologies to support digital instrumentation and control integration for monitoring and control as well as for noting areas of improved reliability and areas requiring further information and research. Universities performing this research will be expected to produce results that integrate multiple mechanistic processes.

NEUP Workscope Descriptions (6/6)

Advanced LWR Fuels (LWRS-4)

The Light Water Reactor Sustainability Program is conducting research and development on the use of silicon carbide ceramic matrix composite nuclear fuel cladding. The goal is to provide improved economic performance and a greater resistance to accident conditions than could be achieved with current zirconium based claddings. Areas of particular interest are the development of radiation resistant silicon carbide ceramic matrix composites, novel fabrication methods, and unique end plug to cladding tube connecting methods.

LWRS

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